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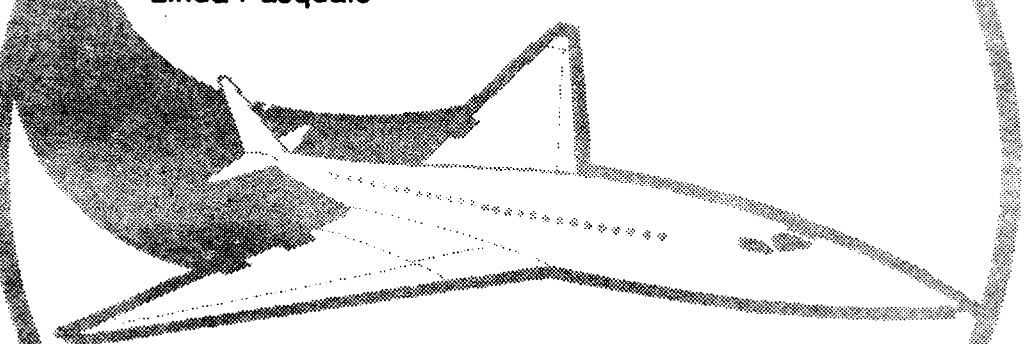
technical note

MLS Mathematical Modeling Study of Philadelphia International Airport Runway 27L

Linda Pasquale



March 1992

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16. Abstract

A mathematical modeling study of the proposed Microwave Landing System (MLS) for runway 27L at Philadelphia International Airport was performed at the request of the MLS Program Office. The study focused on the feasibility of three offset approaches designed to maintain acceptable separation distance from aircraft approaching runway 27R. Modeling was performed using these three approaches, two elevation sites, one azimuth site, and several potential multipath obstacles. Results of the modeling study indicate that the three offset approach procedures would be feasible in this environment. No problematic effects from the airport environment were predicted within the usable coverage volume of the MLS signal.

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EXECUTIVE SUMMARY

A mathematical modeling study of the proposed Microwave Landing System (MLS) for runway 27L at the Philadelphia International Airport was performed at the request of the MLS Program Office. The study focused on the feasibility of three offset approaches designed to maintain acceptable separation distance from aircraft approaching runway 27R. Modeling was performed using these three approaches, two elevation sites, one azimuth site, and several potential multipath obstacles. Results of the modeling study indicate that the three offset approach procedures would be feasible in this environment. No problematic effects from the airport environment were predicted within the usable coverage volume of the MLS signal.

INTRODUCTION

OBJECTIVE.

This study analyzed the potentially derogatory effects of the airport environment at the Philadelphia International Airport on a Microwave Landing System (MLS) for aircraft making approaches to runway 27L. The study was performed using the MLS mathematical model maintained at the Federal Aviation Administration (FAA) Technical Center. A description of the model appears in appendix A.

BACKGROUND.

In March 1991, the MLS Program Office requested a math modeling study for a proposed MLS on runway 27L at the Philadelphia International Airport. The request was accompanied by a drawing of three offset approach procedures which would guarantee the required separation distance from aircraft using runway 27R. The 3° offset approach maintained proper vertical separation from aircraft approaching runway 27R by following a 6° glide slope. This approach is referred to as a steep angle approach. The other two maintained separation by their offset azimuth angles of 8° and 10°, respectively, using a 3° glide slope. The drawing accompanying the modeling request indicated sites for the azimuth and elevation ground stations, but the only quantitative site information provided was the distance of the elevation from the stop end of runway 27L, 5200 feet. This siting is referred to as elevation position 1. Using the approach data, MLS math modeling personnel determined coordinates for an azimuth site and an elevation offset distance that would support the proposed approach procedures. This configuration, and the three offset approaches, are shown in figure 1.

Because this site configuration located the elevation behind the taxiway to the United Parcel Service (UPS) facility adjacent to the runway, a second configuration was developed with the elevation in front of the taxiway, 5700 feet from the stop end (elevation position 2). The azimuth was located at the same site but with the boresite rotated clockwise 2.85° to allow the offset approaches to fall on whole-degree radials. That is, the steep angle approach would be a boresite approach. The other two would be flown on the 5° and 7° azimuth radials, respectively. This second configuration is shown in figure 2.

These two site configurations with their associated approaches provided the basis for the modeling study. Potential sources of multipath were identified from maps, aerial photographs, and panoramic photographs taken from each of the ground station locations. Figure 3 shows the potential multipath obstacles included in this study. Eastern Region personnel provided a drawing of the proposed UPS parking plan for DC-8 and Boeing 747 aircraft at their facility. These aircraft were also included as potential sources of multipath interference. Figure 4 illustrates the UPS parking plan. All aircraft shown were modeled as both scattering and shadowing obstacles.

DATA PRESENTATION AND ANALYSIS

For the first stage of the study, each approach was modeled with all potential multipath obstacles. Because the model limits to 10 the number of obstacles in any single category, the 40 scattering/shadowing aircraft were run in four sets of 10 each and the scattering buildings in two sets. Results showed that, although some obstacles would have scattering or shadowing effects on the azimuth or elevation signals, no errors would occur at the receiver. Plots from this first stage showing the most significant multipath effects will illustrate these results.

The MLS mathematical model presents scattering information as a plot of the multipath-to-direct (M/D) signal ratio (in decibels) for the six sources of highest multipath for the given scenario. The highest M/D ratio was caused by effects of scattering aircraft No. 6 on the azimuth signal for the steep angle approach. The scattering plot for this scenario is provided in figure 5. However, no errors occurred at the receiver, as is shown in the path following error (PFE) plot for this scenario, figure 6.

The most significant shadowing effects were observed on the azimuth signal for the 10° offset approach. The plot of direct signal amplitude produced by the model for this scenario is presented in figure 7. The model does not identify the individual obstacles causing this effect. By running each shadowing aircraft individually, the most significant contributors to the observed shadowing effect were identified as aircraft Nos. 11 to 14. However, as with the scattering effects discussed above, these shadowing effects did not cause errors at the receiver, as illustrated in figure 8.

For the second stage of the study, a composite scenario for each flightpath was created from the obstacles showing the greatest effects in the first round of modeling for that flightpath. Not surprisingly, the results from this second round of modeling were identical to those from the first round. That is, aircraft No. 6 produced the highest scattering effect, and aircraft Nos. 11 to 14 produced the highest shadowing effect. Neither scenario predicted errors at the receiver.

Finally, a third round of modeling was performed to evaluate the effects on the coverage volume of the MLS. In this third stage, the obstacles producing the highest effects in stage two for each of the siting geometries were combined into a single scenario and run with two partial orbit flightpaths, each with a radius of 7 nautical miles (nmi) from the stop end of runway 27L. One orbit at 1.0° elevation evaluated the lower limit of usable coverage. To accommodate this flightpath, the model's lower scan limit for the elevation system was set at 0° (usually 0.9°). The second orbit, at 3°, evaluated the main volume of coverage. This strategy identified the problem areas within the coverage volume for each of the siting geometries.

With the elevation at position 1 (5200 feet from stop end), the model predicted an out-of-tolerance error at an azimuth angle of 29° for the elevation signal at the lower limits of coverage (1° orbit with elevation scanning down to 0°), as shown in figure 9. By modeling each shadowing aircraft separately, the source of this error was identified as aircraft No. 12. The azimuth signal remained virtually unaffected even at this low elevation angle (see figure 10). At the higher elevation angle of 3.0°, the elevation system still showed the effects of aircraft shadowing, but the errors were within acceptable tolerance limits, as shown in figure 11. As before, the azimuth signal was not affected.

Partial orbit flightpaths produced similar results for the siting configuration with the elevation station at position 2 (5700 feet from stop end). That is, shadowing produced out-of-tolerance errors for the elevation system at the lower elevation angle (1.0°) at azimuth angles of 22° and 30°. The sources of these errors were identified as aircraft Nos. 16 and 14, respectively. These errors were reduced to within-tolerance magnitudes at the higher elevation (3°) because the aircraft were no longer within the line-of-sight of the receiver. Figures 12 and 13 illustrate the control motion noise (CMN) plots for the elevation system at the two orbit elevation angles. As before, the azimuth system (not illustrated) showed no significant interference.

CONCLUSIONS

This study concludes that, given the Microwave Landing System (MLS) siting geometries presented here, the three offset approaches desired for runway 27L can be accomplished without significant interference from the obstacles modeled. It further shows that there will be out-of-tolerance effects on the elevation signal, at azimuth angles beyond 22°, at the lower limit of the usable MLS coverage volume, from aircraft parked at the UPS facility. However, the effects are within tolerance for the main section of coverage volume (at 3°). The azimuth signal shows no out-of-tolerance errors.

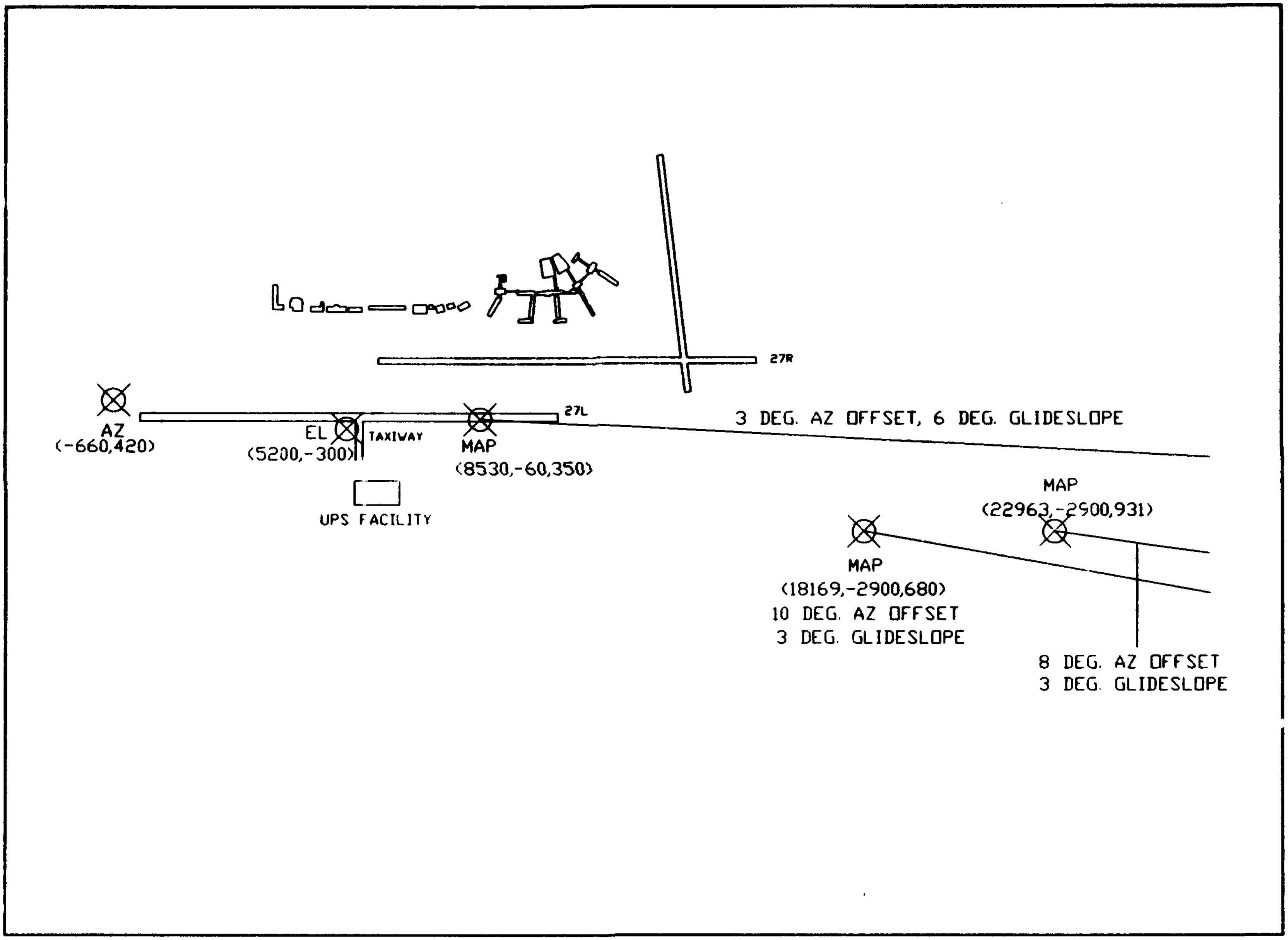

FIGURE 1. SITE CONFIGURATION AND APPROACH PROCEDURES FOR ELEVATION POSITION 1

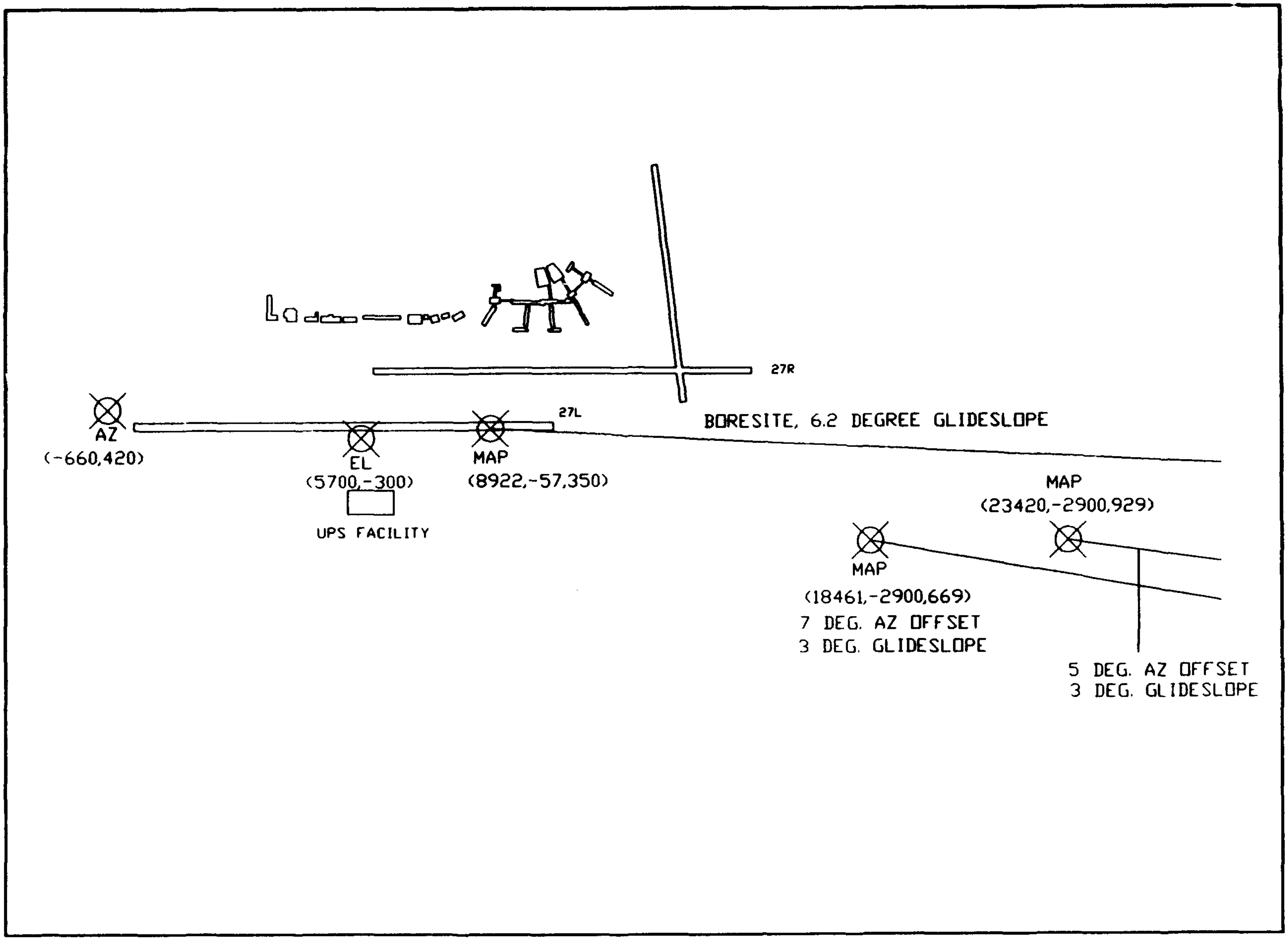

FIGURE 2. SITE CONFIGURATION AND APPROACH PROCEDURES FOR ELEVATION POSITION 2

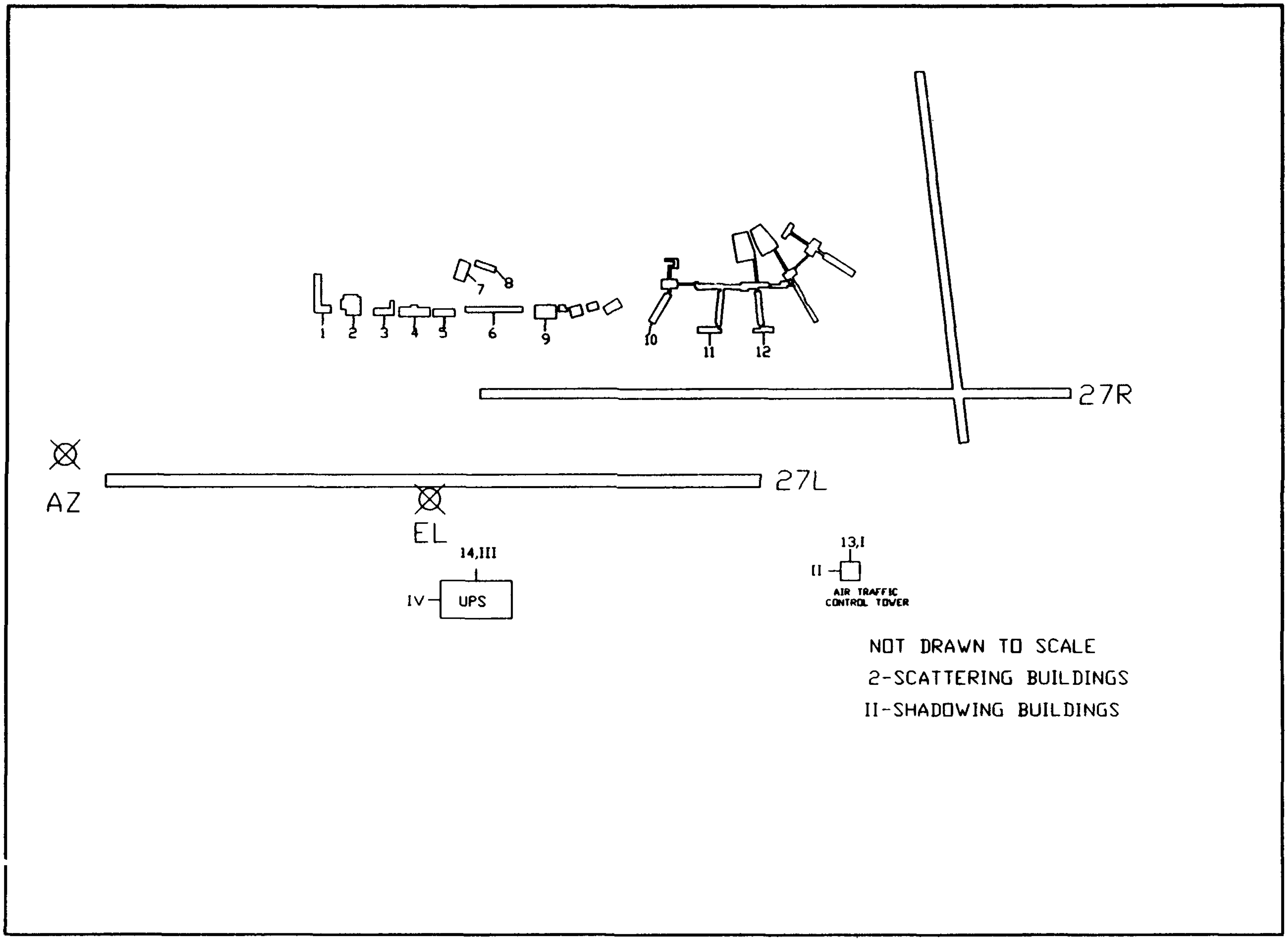

FIGURE 3. SCATTERING AND SHADOWING BUILDINGS

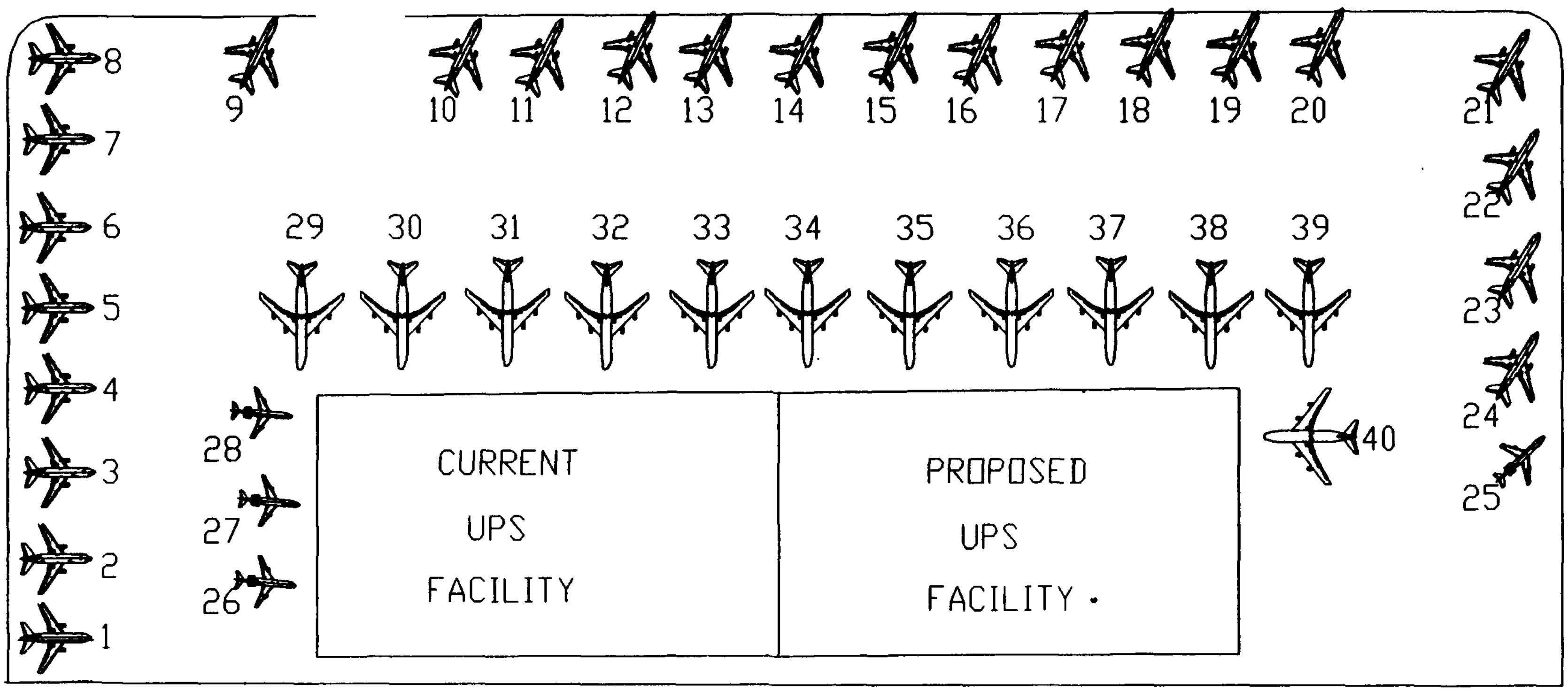

FIGURE 4. UNITED PARCEL SERVICE PROPOSED FACILITY EXPANSION

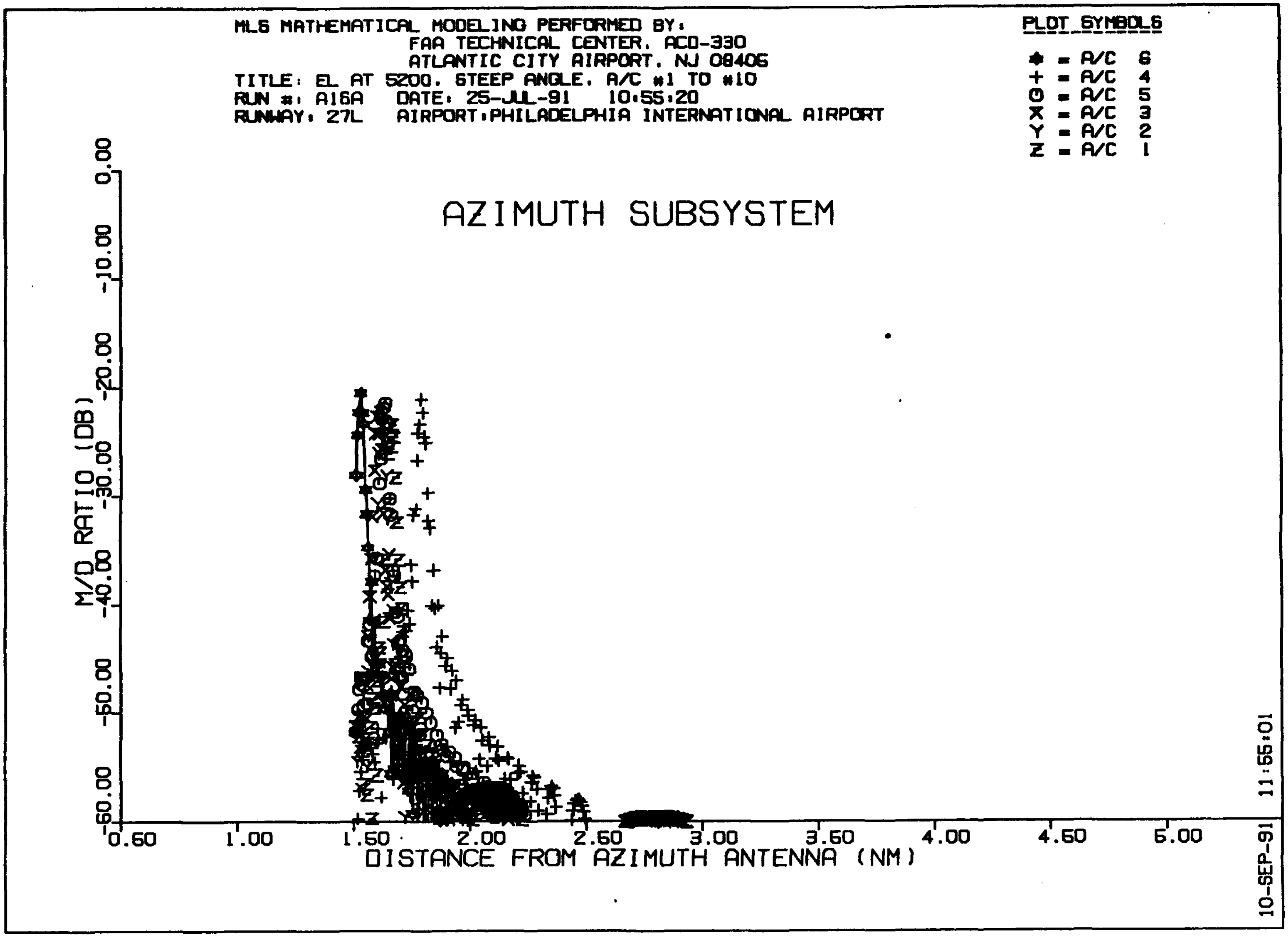

FIGURE 5. MULTIPATH/DIRECT SIGNAL RATIO PLOT FOR STEEP ANGLE APPROACH, AIRCRAFT 1 TO 10, AZIMUTH SUBSYSTEM

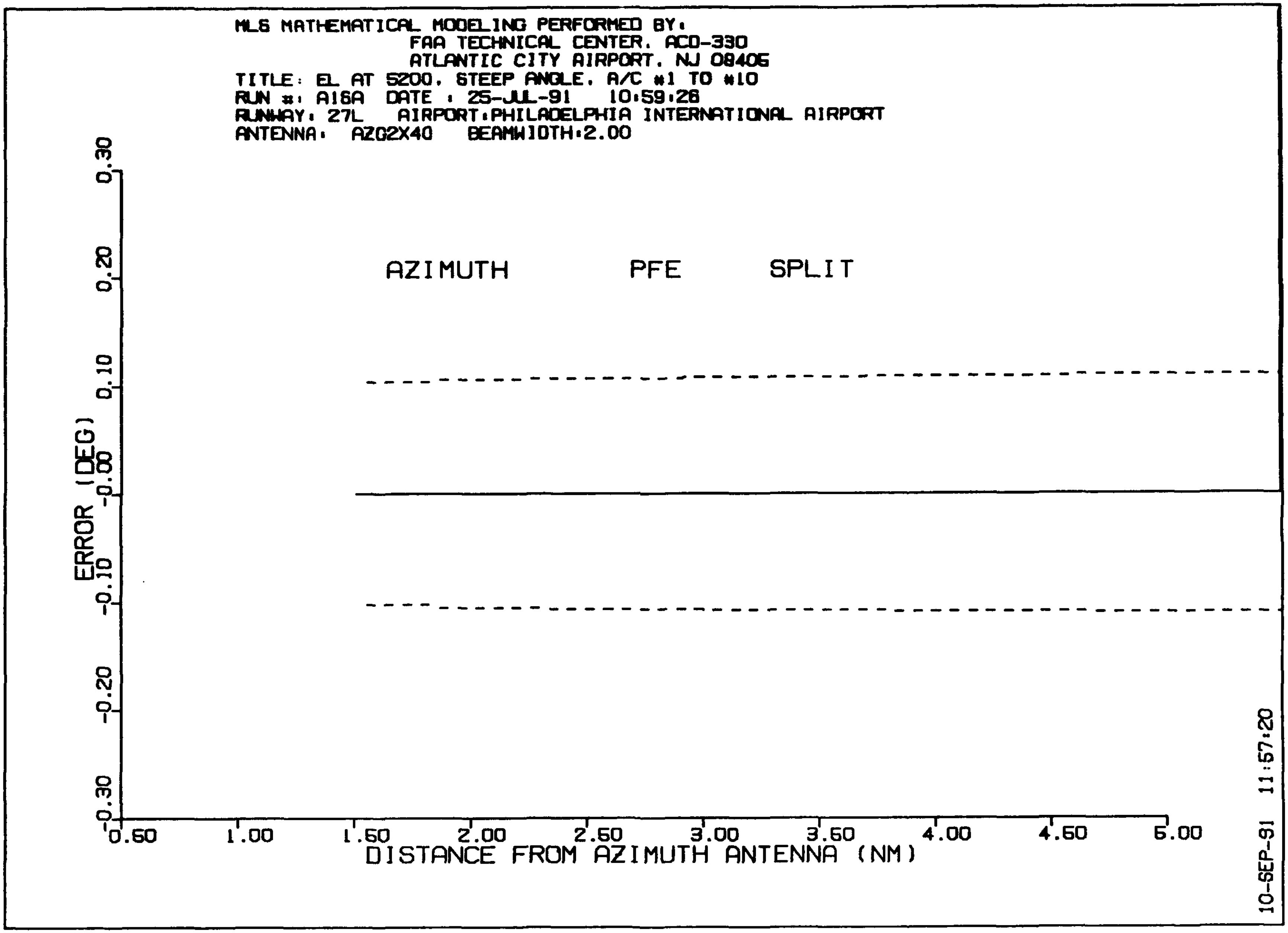

FIGURE 6. PFE ERROR PLOT FOR STEEP ANGLE APPROACH, AIRCRAFT 1 TO 10, AZIMUTH SUBSYSTEM

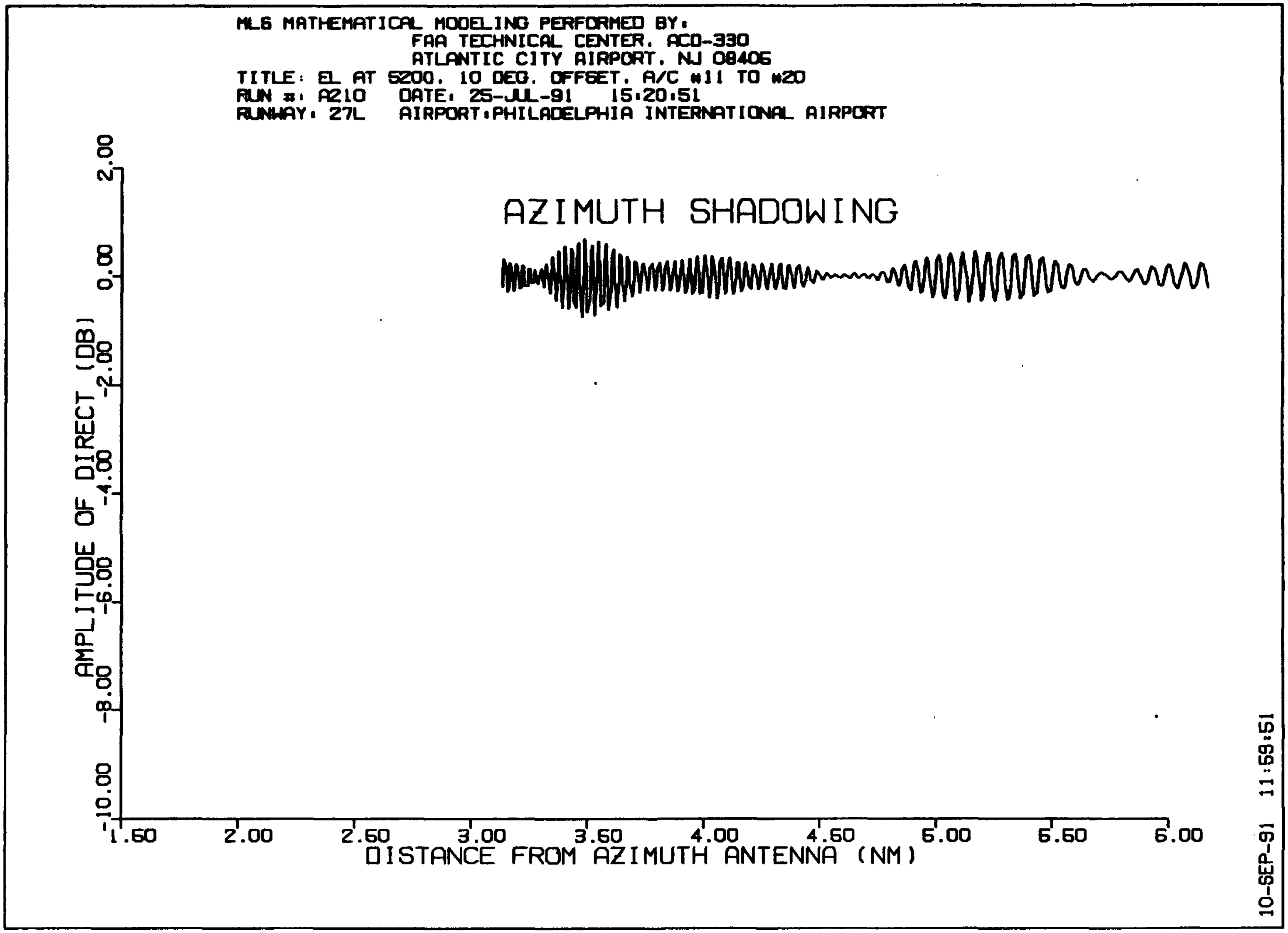

FIGURE 7. SHADOWING PLOT FOR 10 DEGREE OFFSET APPROACH, AIRCRAFT 11 TO 20, AZIMUTH SUBSYSTEM

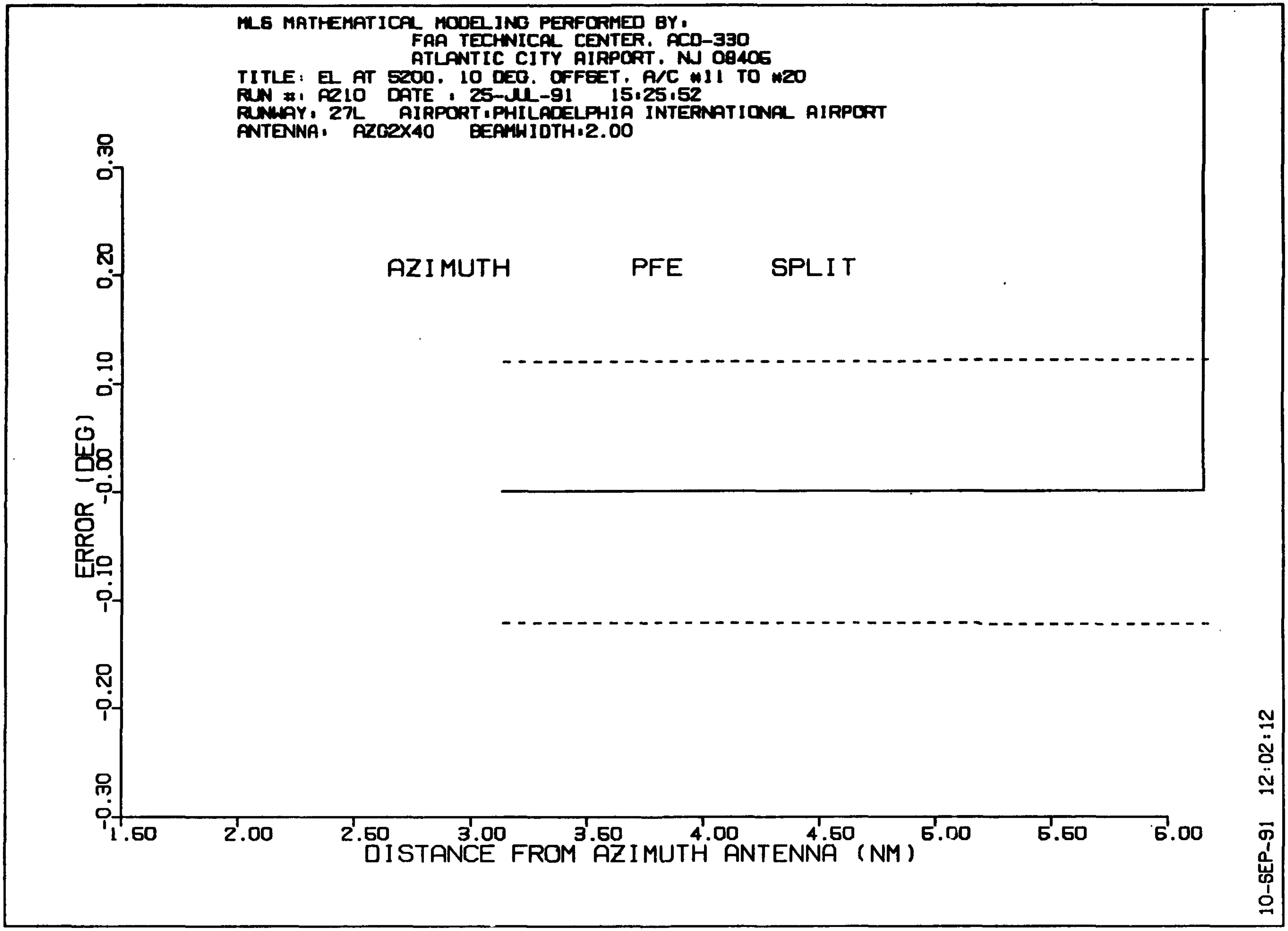

FIGURE 8. PFE ERROR PLOT FOR 10 DEGREE OFFSET APPROACH, AIRCRAFT 11 TO 20, AZIMUTH SUBSYSTEM

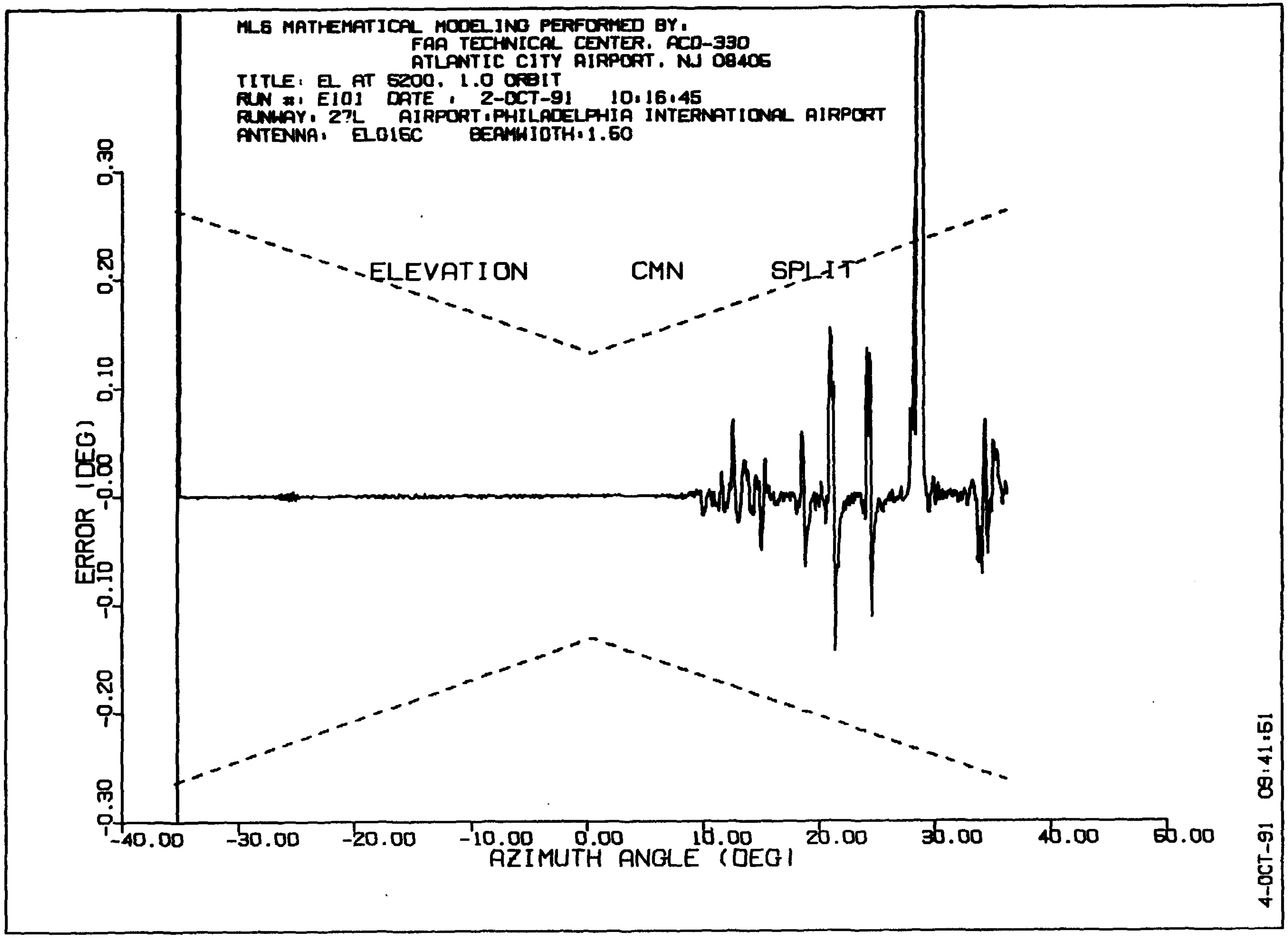

FIGURE 9. CMN ERROR PLOT FOR 1 DEGREE PARTIAL ORBIT FLIGHTPATH, ELEVATION POSITION 1

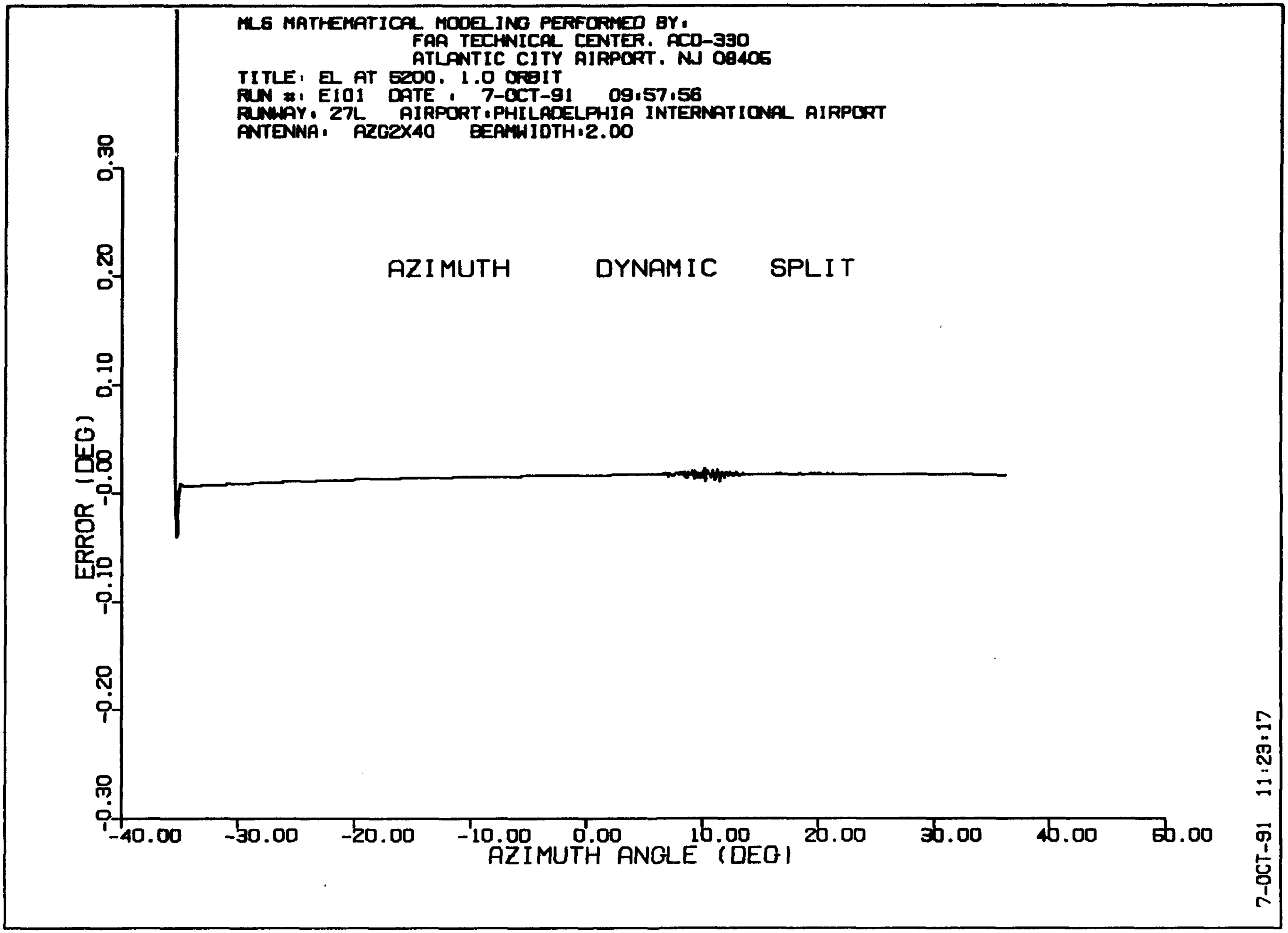

FIGURE 10. RAW ERROR PLOT FOR 1 DEGREE PARTIAL ORBIT FLIGHTPATH, AZIMUTH SUBSYSTEM

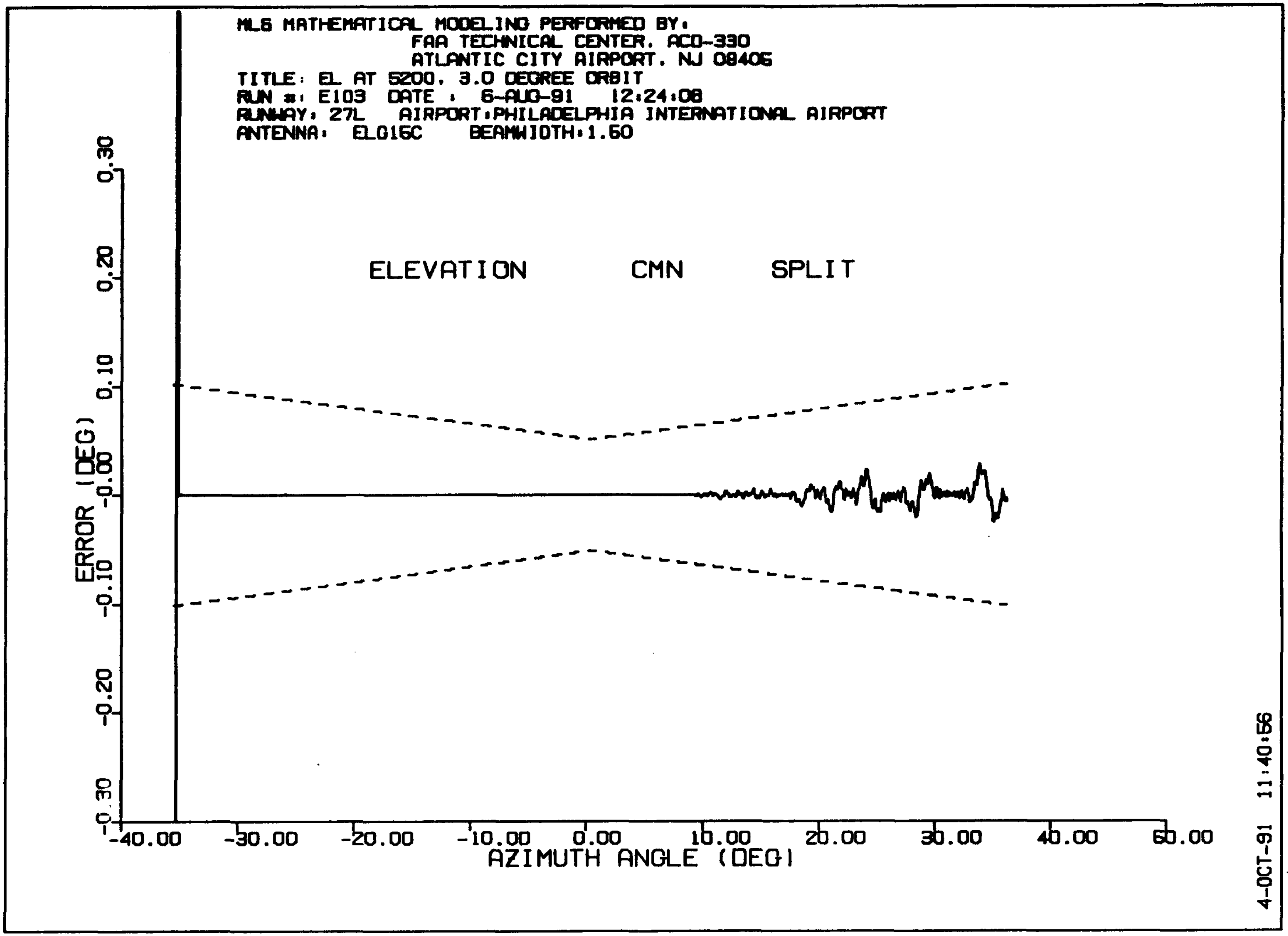

FIGURE 11. **CMN ERROR PLOT FOR 3 DEGREE PARTIAL ORBIT FLIGHTPATH, ELEVATION POSITION 1**

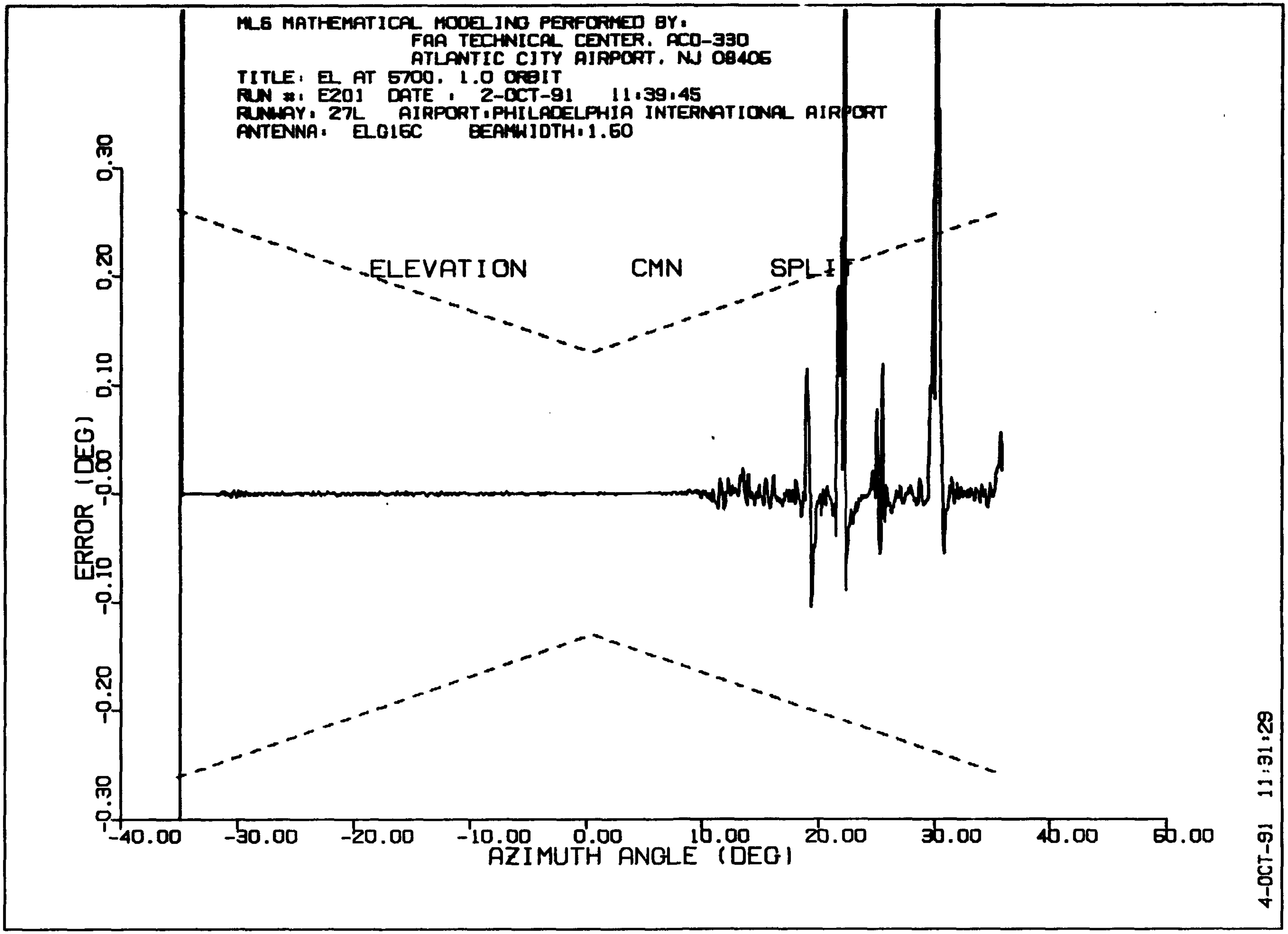

FIGURE 12. CMN ERROR PLOT FOR 1 DEGREE PARTIAL ORBIT FLIGHTPATH, ELEVATION POSITION 2

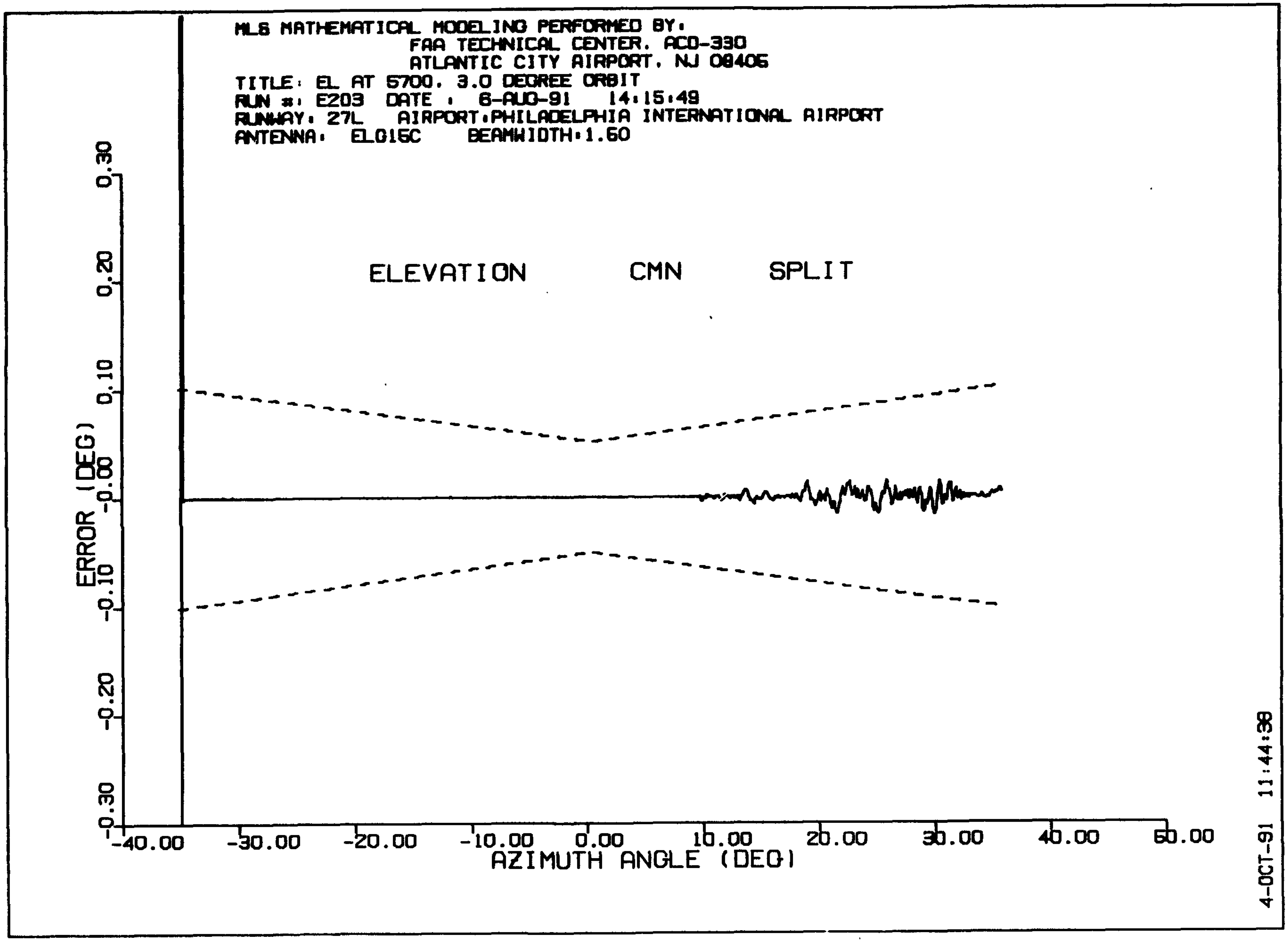

FIGURE 13. **CMN ERROR PLOT FOR 3 DEGREE PARTIAL ORBIT FLIGHTPATH, ELEVATION POSITION 2**

APPENDIX - DESCRIPTION OF THE MLS MATHEMATICAL MODEL

The MLS Mathematical Model is a computer simulation of the effects of an airport environment on the MLS signal. It is used to provide guidance in the selection of MLS and siting configuration for a specific airport environment by predicting the errors due to multipath in that environment.

THE MODEL SOURCE CODE.

The complete model consists of four computer programs. The source code, about 40,000 lines, is written in ANSI standard FORTRAN-77 and has been successfully implemented on a variety of mainframe and personal computers.

A complete site simulation is performed in two stages. The first stage is the execution of program BMLST. This is the propagation (or transmitter) model, a simulation of the signal in space as it interacts with objects in the airport environment. Output from BMLST is written to two files. One file provides plotting information to BPLOTT, a program that plots the multipath and shadowing effects on the signal from each of the ground stations---azimuth (AZ), elevation (EL), precision distance measuring equipment (DME/P). The second file is the input file to the second stage of simulation.

In this second stage, program BMLSR simulates the behavior of an MLS receiver. At each point along the flightpath, the system (or receiver) model evaluates the signal it is receiving in order to distinguish the direct beam from any caused by multipath. Once the receiver is confident that it has acquired the direct signal, it compares this MLS angle with the true position of the aircraft (as defined by the flightpath coordinates, discussed in the section on input parameters). The angular difference between these positions is the error at that flightpath point for that system (AZ or EL). This error is written to an output file which is used by program BPLOTR to plot the error data. BPLOTR also filters the error data with both path following error (PFE) and control motion noise (CMN) algorithms and plots the filtered data with appropriate error tolerances (discussed in the section on output). These plots allow the user to evaluate the receiver errors and determine whether or not they fall within acceptable tolerance limits.

INPUT PARAMETERS.

The model accepts input from an ASCII text input file consisting of 13 sections of input data. The input data fall roughly into three categories: (1) a description of the airport environment, (2) the configuration of the MLS and DME/P systems, and (3) a specification of the flightpath of the receiver. The airport environment is described by coordinate information relative to the runway. The coordinate system assumes an origin at the centerline of the stop end of the runway and is a right-handed coordinate system with the positive X axis along centerline pointing toward the threshold and the positive Z axis pointing up. Each obstacle must be identified in separate sections of the input file as to its potential effect on the MLS signal, i.e., reflective (scattering) or diffractive (shadowing). Obstacles that can be defined include buildings, aircraft (shadowing aircraft can be moving), terrain features, and a runway hump. Obstacles are represented by simple geometric shapes such as rectangles, triangles, and cylinders. User input defines the location of the object and whatever additional information is required (vertical orientation, surface characteristics, velocity, etc.).

For the configuration of the ground systems, the user specifies the location of each transmitter and the type. The user can also indicate a frequency and scan angle limits for each transmitter. The appropriate data for representing the specified transmitter type are loaded into memory by program BMLSR and are used in the evaluation of the signal at the receiver. The receiving antenna is assumed omnidirectional. The propagation portion of the model (BMLST) assumes an omnidirectional transmitter pattern in its operation and does not consider the characteristics of the receiver other than its location in space.

Currently, the path of the receiver is represented as a set of 2 to 36 coordinate triplets (X, Y, Z) which define the locations of the flightpath waypoints. Multipath calculations are made for points between the waypoints depending on the velocity (in feet/second) and distance increment (in feet) defined by the user. These latter values are constrained by the model's assumption of a data rate of 5 hertz for the PFE and CMN filter algorithms.

OUTPUT.

Output from the math model is provided in graphic form by the two plotting programs (BPLOTT for the propagation model, BPLOTR for the system model). Output from BPLOTT includes tables of data and plots (flightpath plots and airport map) that allow the user to verify the input data. In addition, a multipath plot shows the multipath/direct ratio in decibels for each point along the flightpath for each of the six highest multipath sources in the environment. This is accompanied by a plot of the separation angle in degrees (for AZ and EL) or the time delay in nanoseconds (for DME/P). If the user has specified shadowing obstacles, a shadowing plot shows the effect of the simulated shadowing obstacles on the magnitude of the direct signal. For both scattering and shadowing, each transmitter is plotted separately, as requested by the user.

The output from BPLOTR is a plot of the angle error in degrees for each system. The DME/P interrogator is not implemented by the system model at this time. Error plots are provided in four formats. The static error shows the raw error at each receiver point. The dynamic error also shows the raw error with account taken of the movement of the receiver. PFE and CMN plots show the error as filtered by these algorithms, respectively. In addition, tolerance and coverage limits are calculated based on Federal Aviation Administration (FAA) specifications and are displayed on the filtered error plots. The user can then see at a glance whether or not the MLS signal goes out of tolerance at any point along the flightpath. If it does not, it is reasonable to conclude that the airport environment, as defined, will not adversely effect the MLS signal.